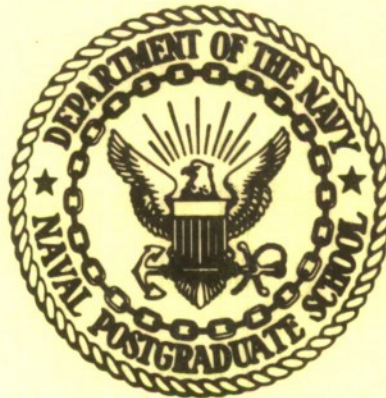


United States Naval Postgraduate School



A REVIEW OF CARGO HANDLING EQUIPMENT

by

RICHARD C. WINFREY

1 October 1971

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ABSTRACT:

A review of the current methods for transferring cargo between a ship undergoing sea induced motion and a relatively stable platform or dock is made. Suggestions for improved equipment are offered as well as a plan for implementing them. Current equipment is felt to be adequate for transferring cargo in calm weather, but leaves much to be desired when transferring cargo in medium to high sea states.

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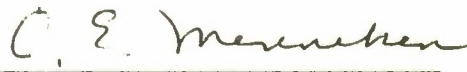
Richard C. Winfrey
Assistant Professor of
Mechanical Engineering

Approved by:

Released by:



R. H. Nunn
Chairman
Department of
Mechanical Engineering



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Dean of Research Administration

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INTRODUCTION

The operational requirements of the Mobile Ocean Basing Systems concept necessitates the ability to load and unload cargo and personnel with minimum concern for sea state. Due to size and configuration, the M.O.B.S. platform should be fairly stable, or steady in the water. However, ships tied up alongside will undergo sea induced motion that may even be exaggerated due to waves incident from the open sea being reinforced by waves reflected and refracted from the M.O.B.S. structure.

Since cargo transfer even at medium sea states is undesirable with present techniques, methods and requirements must be determined which will permit routine cargo transfer in medium to high seas. It has been the purpose of this two month study to first investigate the literature with regard to what equipment is available for cargo transfer, and then, of more importance, to suggest methods for improving cargo transfer. As a result, this report will be divided into three sections: Conventional handling equipment and methods, motion compensating equipment and methods, and suggestions for improvement of existing equipment or new equipment. Full attention has been given to the problem of lifting the cargo from the ship and placing it on the M.O.B.S. platform. It has been assumed that the cargo is accessible from above, such as through a cargo hatch. Any special handling equipment required aboard ship to place the cargo in an area which makes it accessible from above has not been considered. However, as various methods are compared in the report, the need for special equipment will be discussed.

The philosophy used in assessing various transfer methods is that in order to transfer cargo smoothly, the cargo must be firmly constrained against unwanted motion in 6 degrees of freedom (roll, pitch, yaw, heave,

surge, and sway). If, for example, only heave compensation is employed, i.e., one constraint, then the cargo may swing in a pendulous manner and the transfer will not be smooth. A second aspect of the philosophy has been that whatever method is used, it should be capable of handling containerized cargo.

One surprising result of the literature search was the almost complete lack of information available on motion compensated cranes. A wealth of information is available regarding equipment for unloading containers in protected ports, but if motion compensating cranes are being built, they are either unsatisfactory or are just not being reported in the literature. For this reason, it is suggested that an analytical study be made. This study should be made from the structural as well as automatic controls point of view. The study would serve to define the important parameters of a cargo handling device, and show how the various parameters interact.

There is no question that present technology is capable of developing better transfer methods. The extra cost involved in providing a more sophisticated system would be more than offset by the added ease in handling cargo, as well as the obvious increase in safety.

Conventional Cargo Handling Equipment

A number of conventional methods for handling cargo are available and are worth mentioning since they might be capable of providing at least a partial solution to the transfer problem. These methods include Burton, Housefall, Highline, helicopter, crane, and special purpose container crane. It should be emphasized that all of the above (except the Housefall method) have a common, basic disadvantage that once the cargo is even

slightly lifted from the deck, it becomes pendulous and hence potentially dangerous. Thus, any improvement must provide some method of eliminating the unwanted free motion of the cargo - i.e., the same constraints which were originally supplied by the friction between the deck and the cargo must then be supplied by the transfer method once the cargo is free of the deck. Further, any method which does not use the ship as a reference (i.e., not mounted on the ship) must also provide for some type of heave compensation.

Burton, Housefall, and Highline methods [1]-[3],[6],[18],[21],[30]* are roughly similar in that a line is passed between ship and platform and suspended from some high point at each end. (Fig. 1) All have the advantage that the ship may undergo any motion during transfer, but the Burton and Highline methods still have the basic disadvantage discussed above (i.e., a pendulous cargo). One major advantage of the Housefall method is that the Housefall block may be raised and lowered. This permits a minimum pendulous length for the suspended cargo, and advanced versions of the Housefall block mechanism are under study at Hunters Point Naval Shipyard. The Highline method has been adapted by the San Francisco Bay Naval Shipyard in developing a method for transferring cargo from ship to a beach head. The method was felt to be successful although no attempt was made to test it in heavy seas. A major disadvantage of all three methods is that a large percentage of the load carrying capacity of the line is used to keep the cargo up and out of the water, and the cargo is only a small percentage of the load capacity of the line. Typical maximum load capacities vary from 3,500 lb to 12,000 lb - the latter being of fair amount but still falling short of being able to support a 20 ton container.

*Numbers in brackets refer to references listed in the Bibliography.

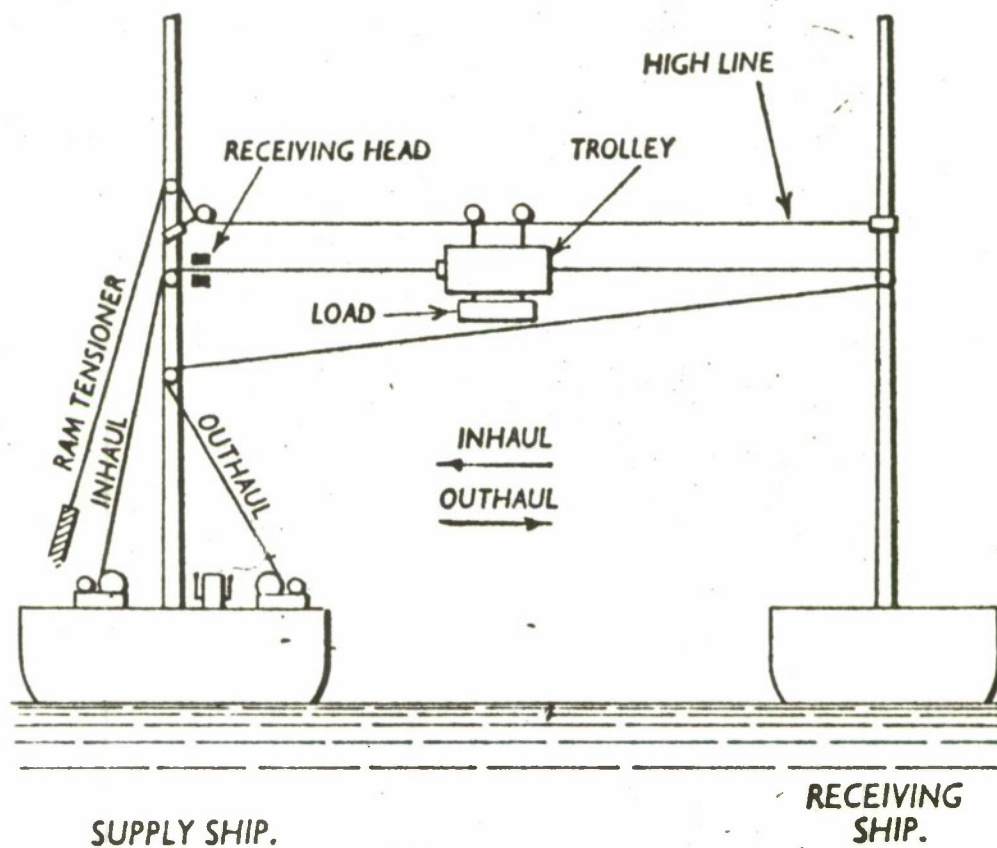


Figure 1 Conventional Transfer Between Ships

Also, some sort of equipment is necessary to place the cargo in position to be lifted from the ship.

Transfer methods using helicopters are presently employed, [29],[39], with cargos as large as containers being accommodated. (Fig. 2) The major disadvantage is the cost of equipment and the basic problem of pendulous mass as well as lack of heave compensation. One proposed method for overcoming the heave compensation problem is to tie the helicopter to the deck while it is hovering above the cargo. Needless to say, this method is not too popular with helicopter pilots; however it does offer a quick solution to the transfer problem. This helicopter tie-down method might not be too objectionable if a good, fail-safe, quick release mechanism were designed to free the helicopter in case of any mishap.

Cranes of all configurations are, of course, in general abundance on most cargo ships as well as on platforms and fixed docks, but all have the basic disadvantage of lacking motion compensation in 5 degrees of freedom for a ship mounted crane and 6 degrees of freedom for a platform or fixed dock-mounted crane. A number of these cranes are discussed in the literature, [5],[9],[13]-[17],[24],[25],[31] but these are intended for use in protected harbors to unload ships and/or shuttle cargo about on shore (Figs. 3 and 4). It is significant to note that most of the new equipment discussed in the literature are designed to handle primarily, if not solely, container cargo.

A good discussion was found ^[40] regarding the problems of unloading AKA and other similar type ships. The unloading rate is fairly good during calm weather, but is effected by the type of boom and winch rig being used, the effectiveness of the mechanical equipment, the experience of the crew,

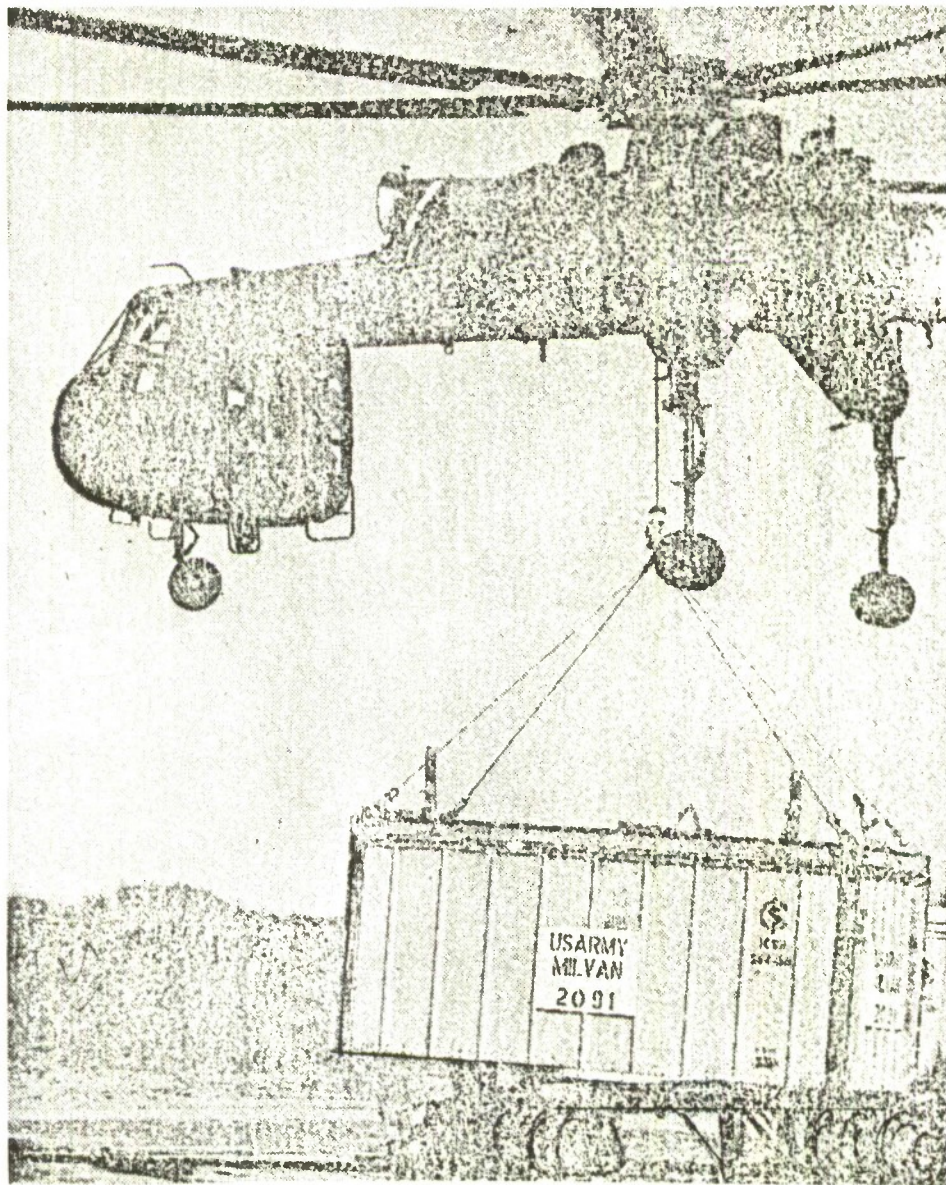


Figure 2 Sikorsky CH-54 Lowering a Container

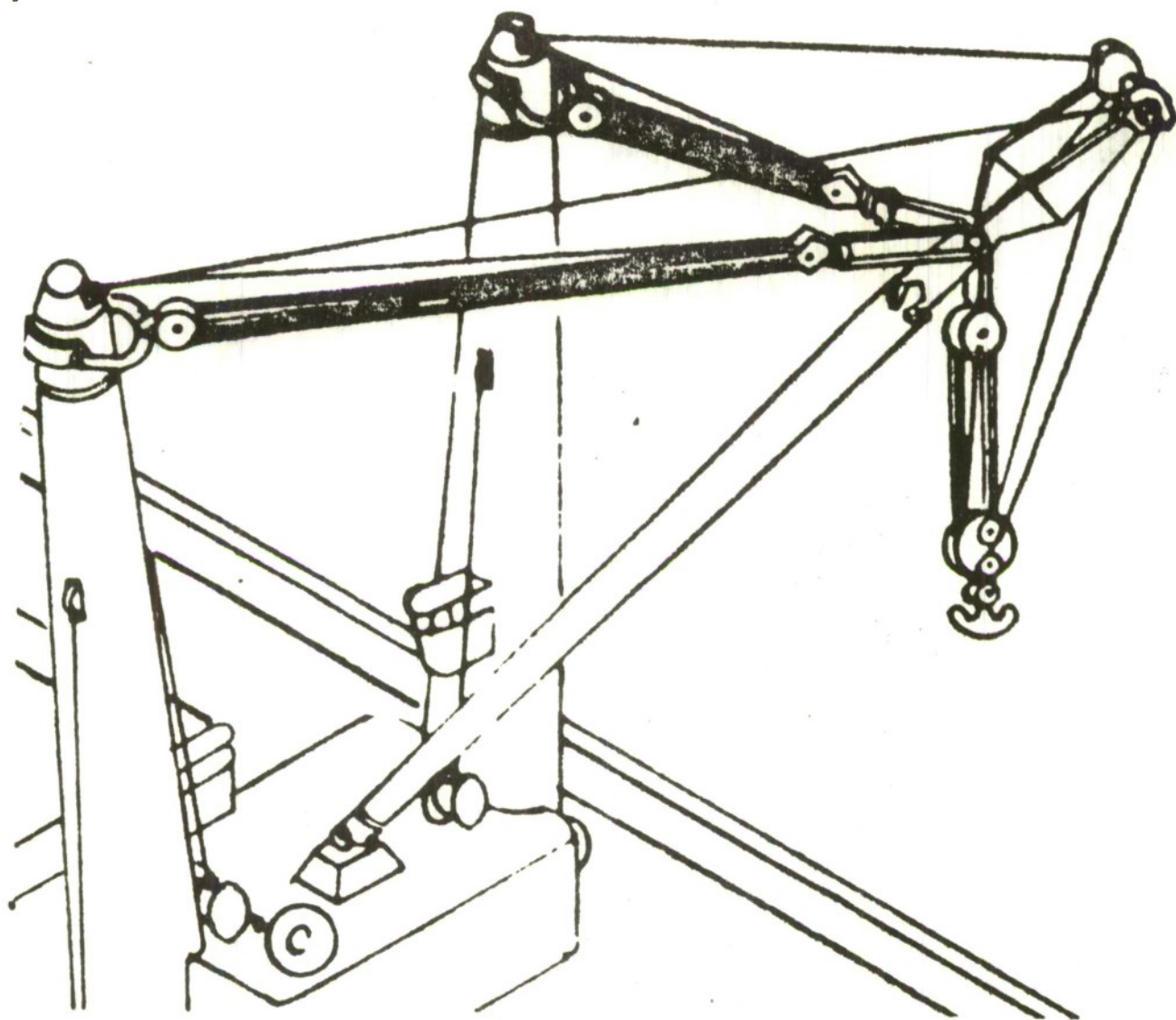


Figure 3 Stuelcken Heavy-lift Rig

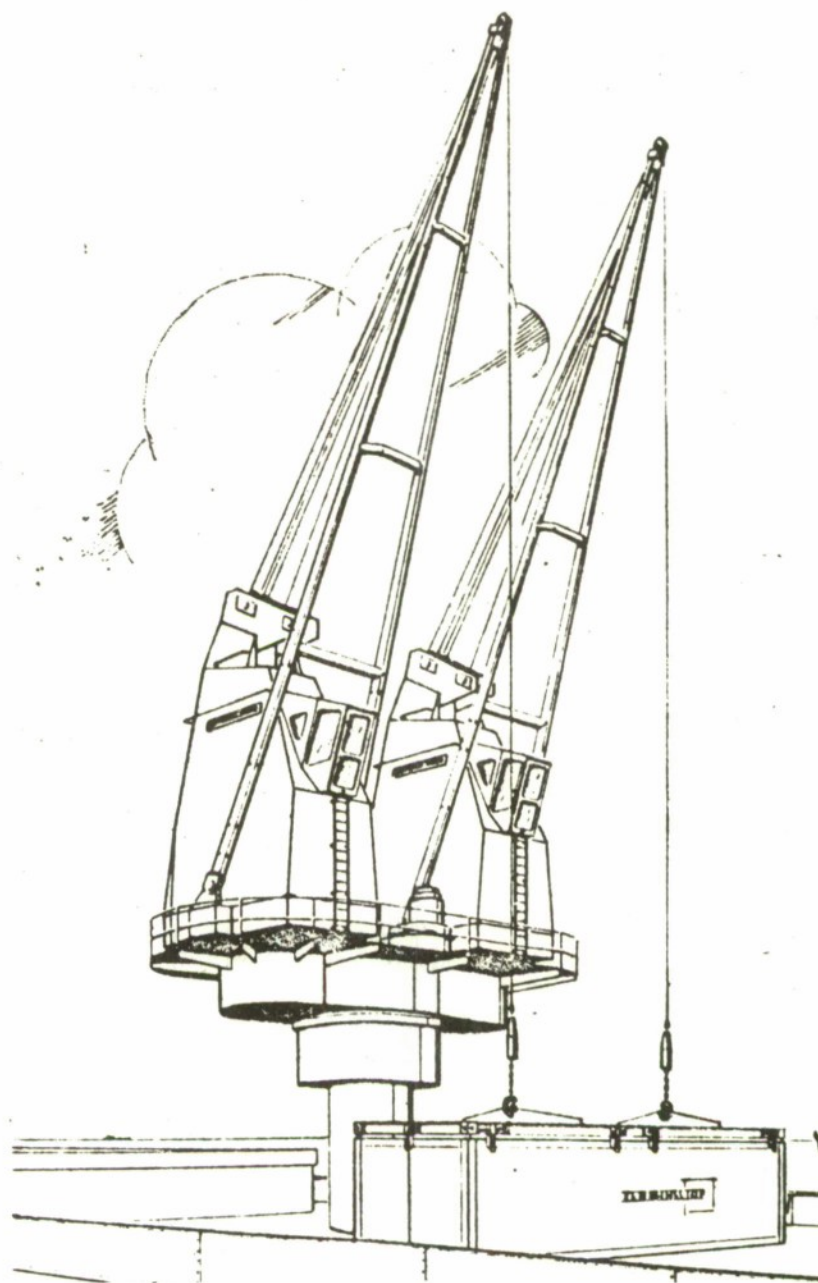


Figure 4 Giessen-Figee Twin Cranes

and the weather conditions. The cargo transfer rate can be reduced by as much as one half if the weather is severe. Fork lift trucks and pallet jacks are needed to move cargo from its stowage location in the hold of the ship to the hatch square where it may be picked up with a boom and winch rig.

One further idea which would come under the heading of conventional methods is the suggestion to firmly tie the ship to the platform. The constrained ship would then be fairly stationary and could be unloaded with conventional equipment. While this method solves the transfer problem, it creates another problem of how to constrain the ship. Barring some means similar to dry docking, it would be impossible to constrain a ship. That is, a ship is not a rigid body such as a cork, but rather a flexible structure and hence could not survive the stresses induced in firmly tying it alongside. The stresses would, of course, be increased during bad weather when the method of unloading becomes more important.

In summary, the existing equipment available is probably adequate for transferring cargo in fair weather but leaves something to be desired when the seas are heavy. Thus, for a crane to be able to handle cargo smoothly in high seas, it must be motion compensated. Since motion compensation means extra expense for additional equipment, it is probably most desirable to have the crane, or equipment, attached to the platform rather than the ship. Size is another factor in selecting platform mounted equipment. A large boom will be required to reach into a hold and then place the cargo on the platform which may be fairly high above the ship.

Motion compensated cargo transfer equipment will next be discussed, and for the reasons just stated, the emphasis will be on equipment which is either platform or dock mounted.

Motion Compensated Cargo Handling Equipment

To properly discuss motion compensated cargo handling equipment, one should first define what he means by "compensated." At one extreme is the manually operated, conventional crane where the operator tries to match the motion of the cargo to the motion of the ship by means of hand levers. In this case, the cargo is allowed to bash against the ship as it sees fit and, indeed, the situation may even be aggravated by the inexperience of the operator. At the other extreme, one could envision the careful placement of a delicate instrument on the deck of a ship while the deck was undulating wildly. Clearly, the proper definition lies somewhere between these two extremes - but where? For a given type of cargo, there must be some optimum choice of equipment and operating specifications. One might be able to define the problem in terms of some maximum velocity differential that can be tolerated between cargo and ship, but the answer is really not that simple. This is because one should also be able to predict the per cent probability of damage to cargo and ship for a given investment in cargo handling equipment. That is, for a given investment in equipment, a certain performance can be expected. Then, given this performance and type of cargo, the per cent loss in cargo through damage could be predicted. Thus, a strong analytical investigation needs to be made to answer such questions as "Can I use a 100 hp motor, or do I need 100,000 hp to achieve some given maximum permissible velocity differential?" With this in mind, the following paragraphs will describe successively more and more complex equipment which is either commercially available or in some advanced stage of design or development. The reader should keep in mind, however, that while the compensated equipment is an improvement over the uncompensated equipment previously discussed,

the compensated equipment which is available does not come close to providing a satisfactory solution to the problem of smoothly transferring cargo (riding a horse is better than walking but an automobile or jet aircraft are far superior means of travel). Also, there is very little analytical work to support the performance of present equipment and on which to base future designs.

At the bottom of the hierarchy of motion compensated equipment is the constant tension winch. [19],[33],[37] These winches have been in service for a good number of years, and while their reliability may vary from unit to unit, they are at least an accepted piece of equipment. In terms of compensation, they offer some small improvement over an uncompensated winch. However, their major disadvantage is that the controlled variable, i.e., the tension in the line, is not the variable of importance when trying to transfer cargo smoothly. To place cargo on a deck, one is concerned with the relative position and velocity between cargo and deck. Indeed, if the deck is moving up and down, the cargo must do likewise. To constantly raise and lower the cargo means that it must undergo continuously varying accelerations. By Newton's Second Law, a changing acceleration means a changing force or tension in the hoist line. Thus, by definition, a constant tension winch cannot possibly provide adequate motion compensation when transferring cargo.

A second cousin to the constant tension winch is the servo controlled winch used in such applications as maintaining a constant depth for oceanographic equipment. [19],[34]-[37] However, it is important to note a subtle difference in requirements between cargo transfer equipment and depth regulation equipment. A piece of cargo, or load, by virtue of its inertia,

wants to remain fixed in some given position. Thus, for depth regulation, the winch is helping the cargo to do what it intrinsically wants to do in the first place. Not so with cargo transfer. As discussed above, the winch must continuously accelerate and decelerate the cargo in a continuous effort to match the motion of the ship. The difference between the constant tension winch and the servo controlled winch is that the latter uses a position or velocity type of feedback to control the motion of the load while the constant tension winch uses a force feedback and is hence less effective. The use of velocity feedback means a more sophisticated system with the accompanying advantage of better or closer control and the disadvantage of higher cost. One servo controlled winch in an advanced state of development^[37] makes use of a gyro-stabilized vertical accelerometer and integrator to obtain the ship's heave velocity. A signal proportional to the velocity of the ship is obtained from the integrator and fed to the control system of the winch to maintain a cable velocity equal to zero relative to the earth. Since integrators may be thought of as accumulative adders, they not only accumulate the acceleration signal from the gyro, but also will accumulate small error signals which are always present. The result is that such a system will drift with time unless proper compensation is made.

Next, and last, are the motion compensated cranes.^{[8],[28]} Several are supposed to be available commercially, but inquiries made by this author to engineers working in the field raised the question of whether the cranes have widespread use or are merely prototype models in some stage of design. In any event, they may be classed as true motion compensated cargo transfer devices - as opposed to the previously discussed motion

compensating devices. All of these units use some form of motion feedback to control the position of the cargo relative to the ship. (Figs. 5, 6, and 7) However, even though these cranes are close to the present state-of-the-art in motion compensated cargo transfer equipment, they only provide for compensation in the heave direction, and how well they perform is not clearly stated. This relates back to the question asked at the beginning of this section regarding what is meant by compensation. Also, these cranes have the disadvantage of allowing the cargo to become pendulous after it has cleared the deck. The Northern Line version partially takes this problem into account in a passive way. Dampers are attached to the load to prevent large amplitude swinging of the cargo. However, no attempt is made to match the sway motion of the ship. To properly evaluate such equipment, one needs to know, for example, what the frequency response of the equipment is for various values of load. The frequency response curves show the ability of the equipment to follow an input signal as the signal varies in frequency and amplitude, and would hence allow some prediction of the equipment's ability to follow the motion of the ship as well as allow the possible prediction of damage.

In conclusion, it may safely be stated that while equipment is available which will transfer cargo in a smoother manner, there is still a great deal of work to be done and improvements to be made. Equipment needs to be built which will handle container sized cargo and still respond well in rough weather. The equipment described above could be thought of as merely a starting point with many limitations. To do a proper job will require a great deal of analysis and testing. To properly define all the important design parameters and show how they interact is the next step, and this will be discussed in the following section.

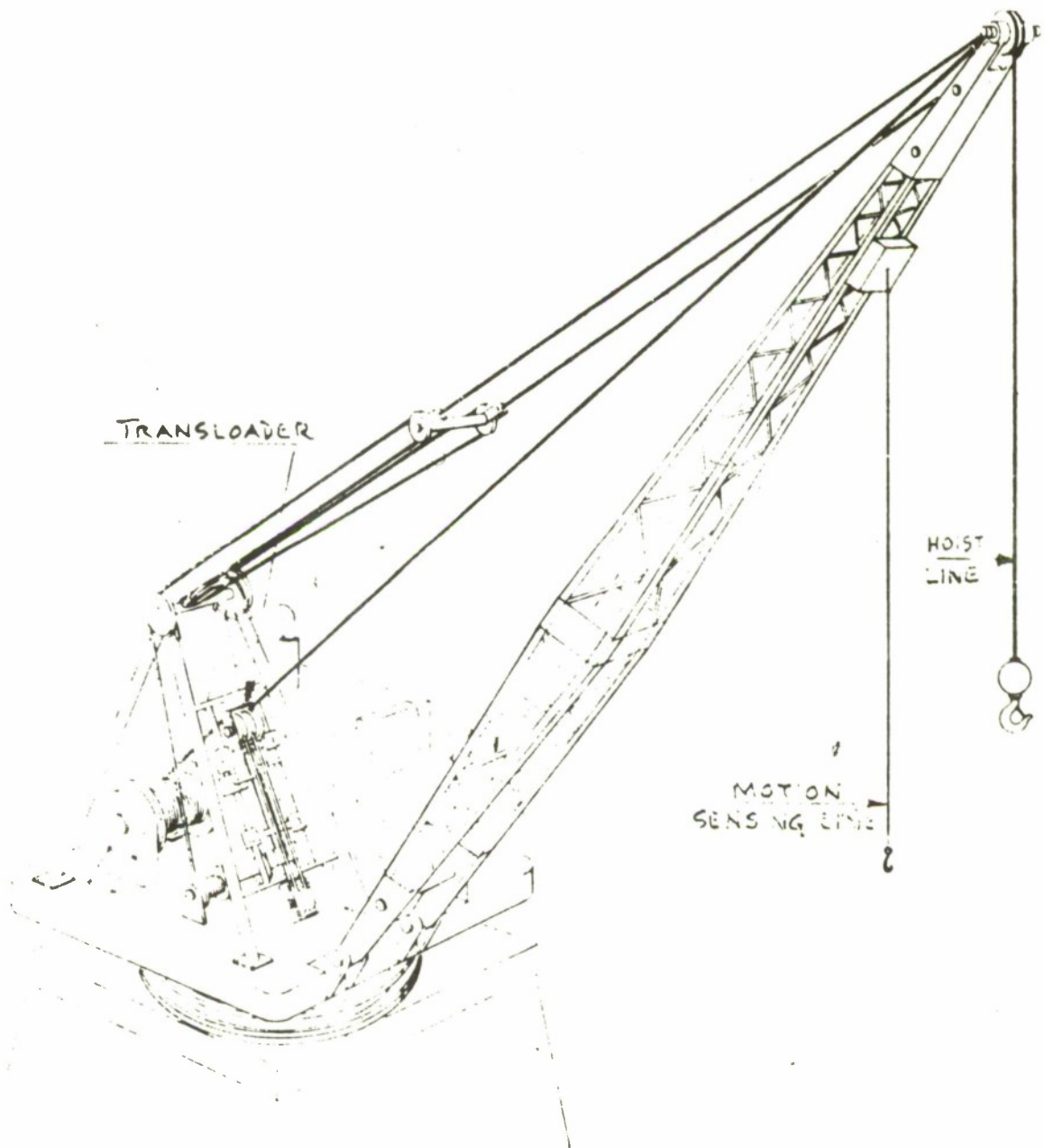


Figure 5 Rucker Transloader Crane Assembly



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 Max. hook speed during automatic tensioning—300 FPM.
 Boom extend speed—4.3 FPM.
 Boom retract speed—7.04 FPM.
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Figure 6 Northern Line DRV Crane

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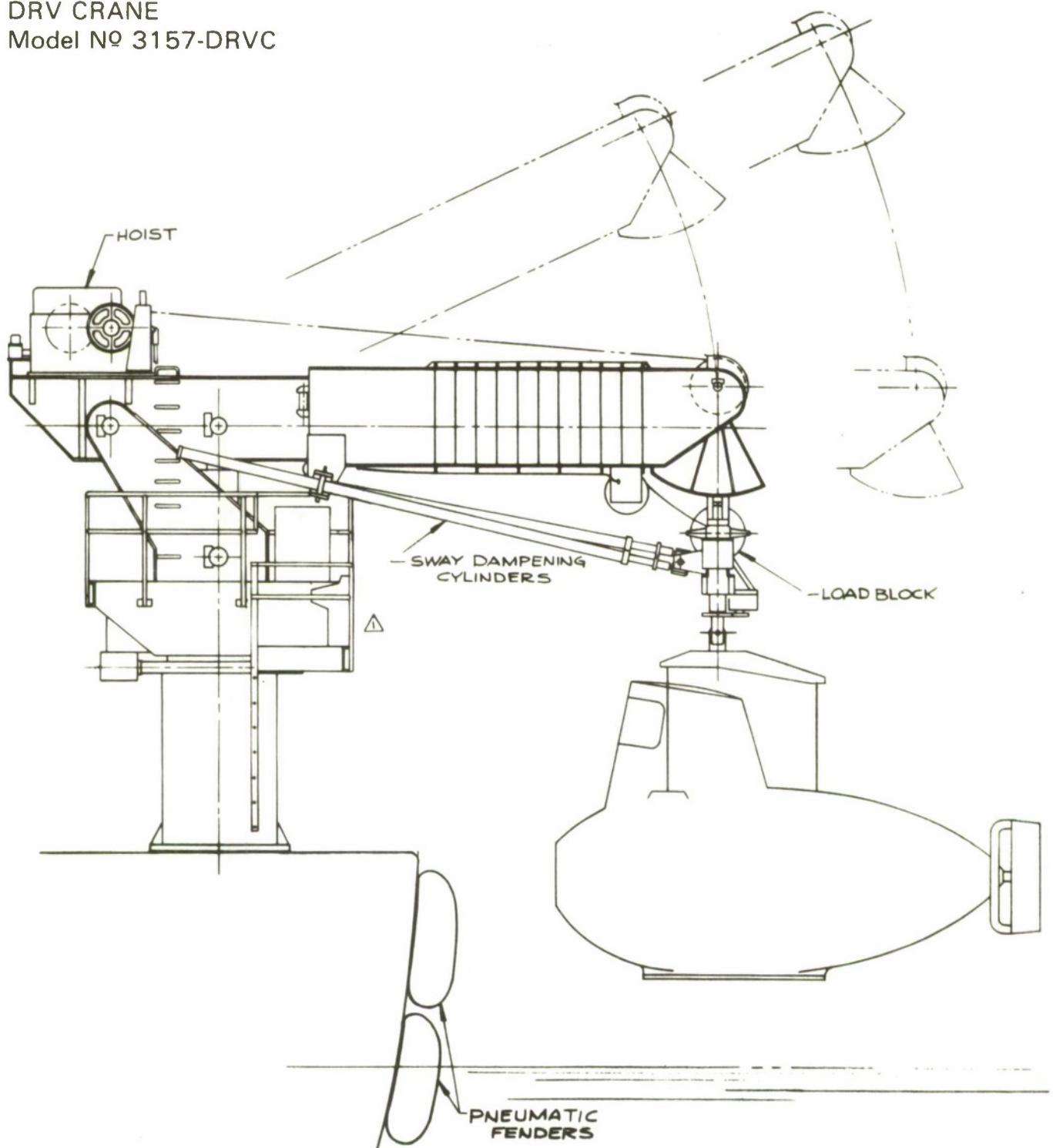


Figure 7 Northern Line DRV Crane

Recommendations and Conclusions

The successful transfer of cargo from ship to platform under good weather conditions is a routine task and the equipment is certainly adequate. However, as the weather becomes worse and worse, the ability to transfer cargo safely is more and more diminished. To counteract the effect of the weather, better equipment is required to accomplish the transfer. The present state-of-the-art in transfer equipment is fairly elementary, and it is recommended that analytical studies be made so as to better define the design variables and the design problem areas. The fundamental problem of cargo transfer and one method for solving this problem may be outlined as follows:

1. The ship exerts forces on the cargo, and these forces cause the cargo to have the same motion as that of the ship.
2. It follows that a motion compensated crane must be capable of exerting the same forces on the cargo as those forces exerted by the ship. That is, during cargo lift off, the application of force on the cargo must be smoothly transferred from the ship to the crane.
3. To exert forces in a precise manner, the pendulous length to the cargo, when suspended from the crane, should be as close to zero as possible.
4. It then follows that the tip of the crane should reach into the hold of the ship and be capable of positioning itself at the cargo.

Note first that the problem raised by item 2 is not alleviated by mounting the crane on the ship. This problem was briefly discussed in the section on conventional equipment. Secondly, note that the solution proposed by items 3 and 4 are independent of the crane's mounting location. It is assumed that the most general problem is to be analyzed - that is,

compensation is to be provided for six degrees of freedom. This general approach permits one to look at more simple models at a later date should they prove feasible or become of interest.

In line with these suggestions, the configuration shown in Fig. 8 might be considered. Shown is a small, articulated crane which has been converted from a commercially available backhoe. The backhoe has hydraulic drive for both azimuth and elevation travel, and is capable of supporting fairly large loads. An analysis based on kinematics, structural dynamics, and automatic controls could be tied together to produce a fairly comprehensive model of an articulated crane. Also, if the results of the analysis prove to be promising, a test model could be put together at a considerable savings over the cost of constructing a specially designed crane.

The articulated crane of Fig. 8 has sufficient travel to follow any motion under which a ship might be unloaded. However, it is not large enough to reach from the platform to the ship. Therefore, rather than try to compensate a crane with a reach of 100 feet or more, the configuration shown in Fig. 9 should be adequate. The small, compensated crane is attached to a much larger conventional or uncompensated crane with the required reach. The larger crane would be manually positioned in the approximate location of the cargo and then the compensated crane would commence to follow the motion of the ship.

An important part of the compensated crane is the control box (Fig. 8 and 10) which detects the motion of the ship and essentially guides the hook to the cargo. As shown in Fig. 10, the control box is a two axis gimbal for roll and pitch, and also detects changes in vertical position. During operation, the crane operator would locate the tip of the boom

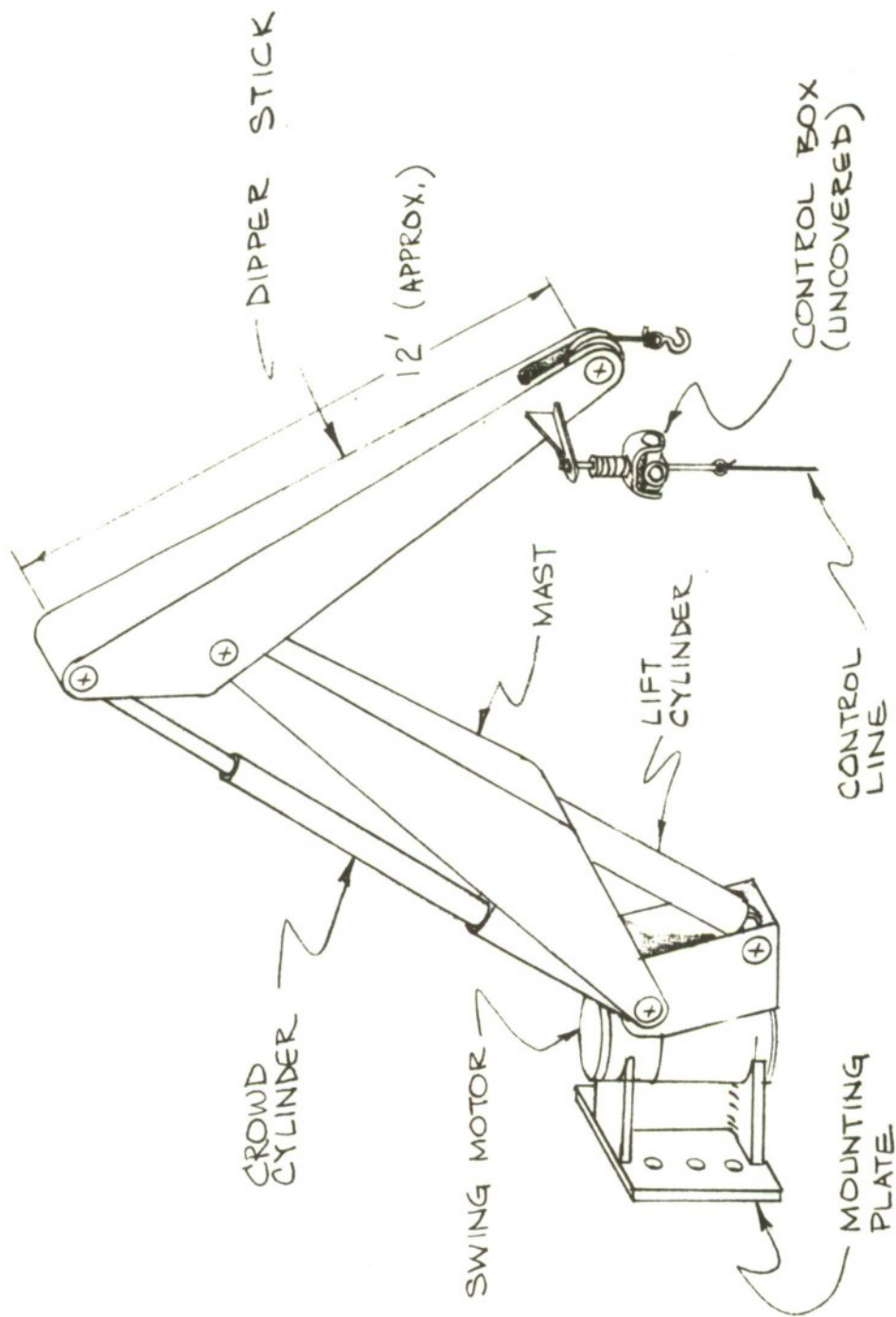


Figure 8 Articulated Crane Adapted from Conventional Backhoe

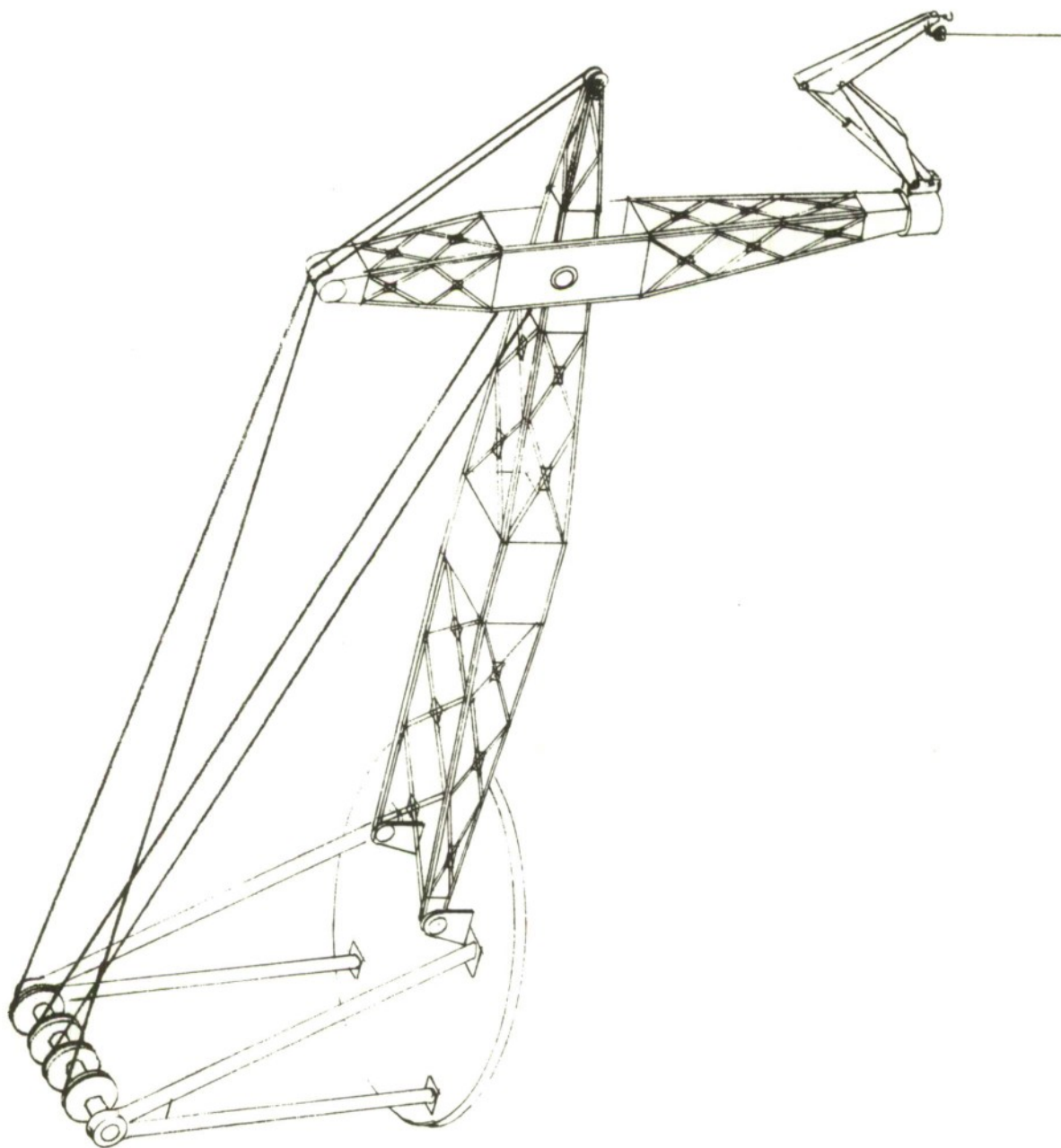


Figure 9 Employment of Compensated Crane on Large, Uncompensated Crane

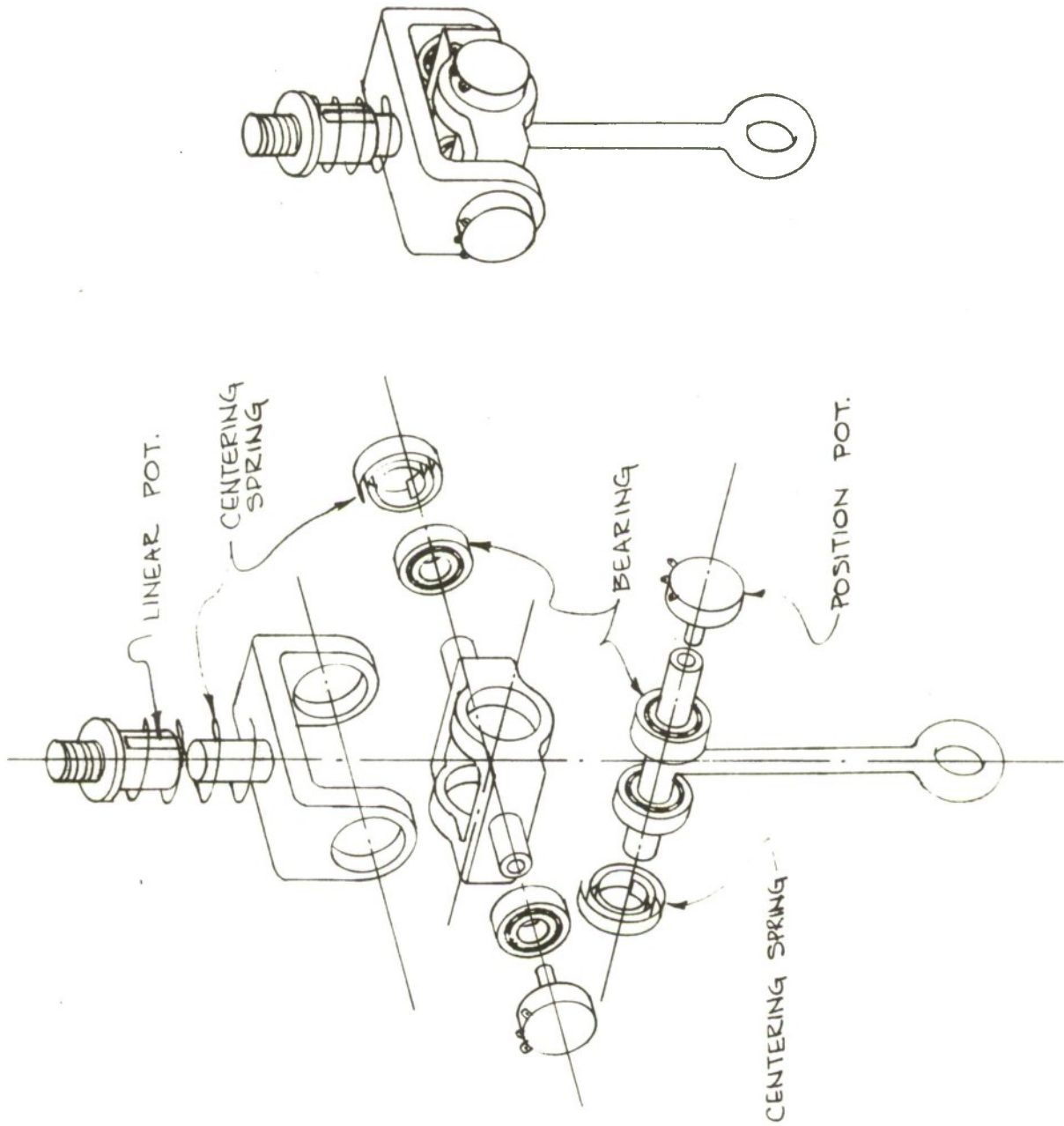


Figure 10 Control Box

approximately over the cargo. A sailor in the hold would then grasp the control line. By pulling down, left, or right, he could guide the compensated crane to the cargo. For example, he might run the control line under his foot. Then, to lower the hook six inches, he would haul in six inches of control line. The servo system would cause the hook to follow the line and stop when the sailor stopped hauling in the line. This ability to very carefully guide the hook should be a great advantage.

In summary, it is suggested that the following steps be taken to further the ability to design better cargo transfer equipment.

1. Formulate a structural model of the crane of Fig. 8.
2. Develop a set of kinematic equations of motion for the crane (including the control box of Fig. 10).
3. Combine items 1 and 2 to obtain a multi-degree of freedom transfer function for an electro-hydraulic servo controlled crane.
4. Perform a parameter study to determine the requirements for motion compensation. A few of the parameters to be studied would be power requirements, effect of size of load, hydraulic pressure, response time, compensation error, crane geometry, etc.
5. Upon the satisfactory completion of the first four items, purchase the necessary equipment and verify the analysis experimentally.

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